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Loss reduction of transmission lines using PSO-based optimum performance of UPFC

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ABSTRACT

Transmission line losses are one of the essential topics and issues in power systems research. Several methods and techniques have been used to reduce these losses, and one of these modern techniques is flexible alternating current transmission systems (FACTS). In this paper, one of the most important types of this technology, the unified power flow controller (UPFC), was used to reduce losses in the Iraqi national grid (ING) 400 kV. This paper presents an efficient method for minimizing losses of transmission lines in the ING system (400 kV) 46-bus approach. A particle swarm optimization (PSO)-based optimum proportional-integral (PI) controller with UPFC was proposed to obtain the optimal location of UPFC and optimum parameters of the PI controller to achieve the objective function of the research. MATLAB coded the algorithm. The Newton-Raphson method was employed to perform load flow analysis. The results showed that the best place for UPFC is buses (14-17) named BGE4 (Baghdad)-AMN4 (Baghdad), and the total active power and reactive power losses decreased from 727.4593 to 579.3874 MW and from 5155.9 to 3971.1 MVAR, respectively and also led to voltage regulation.

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1. INTRODUCTION

Transmission lines are now under more pressure than ever and thus have a greater chance of line failure due to increased demand for electricity and an inability to keep pace due to resource and environmental constraints. Improving system reliability and safety can be as simple as installing new transmission lines. But due to political and environmental factors, this becomes a long process. New technology is being developed to make the electric grid more reliable and safe, such as flexible alternating current transmission systems (FACTS) [1]. The FACTS technology is astonishingly and swiftly integrated with power transmission networks. It can give power transmission lines the boost they need, especially the unified power flow controller (UPFC) type; two converters and two transformers are included, one connected in series with the transmission line and the other in parallel. UPFC controls the flow of actual and reactive power through the transmission line independently by inserting voltage into the transmission line [2]–[4].

Minimizing power losses is one of the primary goals of installing FACTS devices in power grids; therefore, almost all articles dealing with these devices have addressed this issue [5]–[9]. Numerous authors have looked into the advantages of UPFC placement on system performance. However, the best placements for UPFC devices are essential due to their high price. Several strategies, including classical, heuristic, and mixed techniques, are available in the literature for resolving these FACTS optimisation problems. However,

all of these methods have disadvantages in addition to their advantages. Heuristics techniques such as genetic algorithms (GA), differential evolution, particle swarm optimisation (PSO), evolutionary programming, and evolution strategies are commonly employed for optimisation problems. These techniques can calibrate optimal outcomes with less complexity [10].

Research by Kashyap and Rahangdale [11], PSO is used to fix many problems with electrical power transmission networks. It can reduce system losses, improve line voltages, and increase transmission capacity. Salman *et al.* [12] employed GA to identify the best location for UPFC devices to optimize voltage profiles, reduce power losses, control power flow in overloaded transmission lines, and decrease power generation in the local Iraqi network (Diyala 132 kV). Two types of artificial algorithms, imperialist competitive algorithm (ICA) and PSO, were compared in [13], and FACTS devices effects are displayed to minimize network losses. It has been shown that the PSO algorithm with UPFC reduces both active and reactive power losses more than other FACTS device types and intelligent algorithms. Although UPFC has several advantages, its controller design remains a problem because it is a multi-variable controller. Numerous control strategies have been implemented to control UPFC for various power system applications. Qader [14] proposed a systematic technique based on optimal control and tracking with a proportional-integral (PI) controller for the UPFC, desired steady-state behaviour, and a linear quadratic tracker, MATLAB/Simulink model. Deka *et al*. [15] presents the MATLAB/Simulink fuzzy UPFC model based on PI to improve the power quality by correcting the load voltage and changing the active and reactive power. El-Emari *et al*. [16] proposed an optimized PI–derivative (PID) controller for the UPFC; the suggested system uses the algorithm (ICA) to determine the optimal PID free gain values. After optimizing the controller, it is applied to a simple standard procedure, and the results show that the proposed method works well. According to Romasevych *et al.* [17], the gains of the PI controller were calibrated using the PSO; the control system under consideration was a PI controller cascaded with a general plant. Roslan *et al*. [18] proposed a PSO algorithm to improve the performance of the PI controller in a real-time simulation system by finding the optimum values for the PI controller parameters. All of this research implemented the control by Simulink. The following points are the primary contributions of this paper: i) proposed PSO-based optimum PI controller parameters to find the optimum performance of UPFC by controlling the voltage of the two converters of the UPFC device and finding the optimal location of this device. The proposed algorithm is coded in MATLAB code (M-file); ii) the objective function of the research is to minimize the transmission line's active and reactive power loss; and iii) the proposed method is tested on the Iraqi national grid (ING) (46-bus) system.

2. PROPOSED METHOD

To achieve the objective mentioned in the paper's contributions. PSO is used to determine the optimal location of the UPFC and the optimum parameters of the PI controller. The study method is discussed thoroughly: UPFC modelling and the proposed PSO-based optimum PI controller with UPFC.

2.1. Unified power flow controller

The UPFC concept was proposed by Gyugyi [19]. The use of UPFC makes it possible to simultaneously control the impedance of a transmission line, the phase angle, the magnitude of the voltage, and the active and reactive power flow [20]–[23]. As shown in Figure 1 [12], UPFC comprises two voltage-sourced converters, one coupled in a shunt (i.e. STATCOM) and the other in a series ((i.e. SSSC) [24], [25]. By injecting an AC voltage with a controllable magnitude and phase angle in series with the transmission line via a series-connected coupling transformer, the series converter performs the primary role of a UPFC. On the other hand, the main job of the shunt converter is to give or take the actual power that the series converter needs at the common DC link [26]. Figure 2 [12] shows the UPFC's electrical model.

The essential operation of UPFC and the needed to apply PSO to it to find the location and parameters of PI-based UPFC controller on the power transmission network ING (400 kV). As a result, (1) through (16) [12] are used to implement the PSO program. To achieve the given goals that will be discussed using in the following section:

$$E_{vR} = V_{vR}(\cos\ \delta_{vR} + j\sin\ \delta_{vR}) \tag{1}$$

$$E_{cR} = V_{cR}(\cos\ \delta_{cR} + j\sin\ \delta_{cR}) \tag{2}$$

$$\mathrm{Re}\{-E_{vR}I_{vR}^{*} + E_{cR}I_{m}^{*}\} = 0 \tag{3}$$

$$\begin{bmatrix} I_K \\ I_m \end{bmatrix} = \begin{bmatrix} (Y_{cR}+Y_{vR}) & -Y_{cR} & -Y_{cR} & -Y_{vR} \\ -Y_{cR} & Y_{cR} & Y_{cR} & 0 \end{bmatrix} \begin{bmatrix} V_K \\ V_m \\ E_{cR} \\ E_{vR} \end{bmatrix} \tag{4}$$

where:
E_{vR}, E_{cR}: UPFC voltage sources
V_{vR}: the controllable magnitude supplying the shunt converter ((V_{vR} min)≤ V_{vR}≤(V_{vR} max))
δ_{vR}: the phase angle of the shunt converter (0 ≤δ_{vR}≤ 2π)
V_{cR}: the controllable voltage magnitude supplying the series converter ((V_{cR} min)≤V_{cR}≤V_{cR}max))
δ_{cR}: the phase angle of the series converter (0 ≤δ_{cR} ≤ 2π) [12]
bus K:

$$\begin{aligned} P_K = {} & V_K^2\, G_{KK} + V_K V_m [G_{Km}\cos(\theta_K-\theta_m) + B_{Km}\delta in(\theta_K-\theta_m)] + V_K V_{cR}[G_{Km}\cos(\theta_K-\delta_{cR}) \\ & +\delta in(\theta_k-\delta_{cR})] + V_K V_{vR}\,[G_{vR}\cos(\theta_K-\delta_{vR}) + B_{vR}\,\delta in(\theta_K-\delta_{vR})] \end{aligned} \tag{5}$$

$$\begin{aligned} Q_K = {} & -V_K^2\, B_{KK} + V_K V_m[G_{km}\delta in(\theta_K-\theta_m) - B_{Km}\cos(\theta_K-\theta_m)] \\ & +V_K V_{cR}[G_{Km}\delta in(\theta_K-\delta_{cR}) - B_{km}\cos(\theta_K-\delta_{cR})] + V_K V_{vR}[G_{vR}\ \delta in(\theta_K-\delta_{vR}) \\ & +B_{vR}\cos(\theta_K-\delta_{vR})] \end{aligned} \tag{6}$$

bus m:

$$\begin{aligned} P_m = {} & V_m^2 G_{mm} + V_m V_K[G_{mK}\cos(\theta_m-\theta_K) + B_{mK}\delta in(\theta_m-\theta_K)] \\ & +V_m V_{cR}[G_{mm}\ \cos(\theta_m-\delta_{cR}) + B_{mm}\delta in(\theta_m-\delta_{cR})] \end{aligned} \tag{7}$$

$$\begin{aligned} Q_m = {} & -V_m^2 B_{mm} + V_m V_K[G_{mK}\delta in(\theta_m-\theta_K) - B_{mK}\cos(\theta_m-\theta_K)] \\ & +V_m V_{cR}[G_{mm}\ \delta in(\theta_m-\theta_{cR}) - B_{mm}\cos(\theta_m-\delta_{cR})] \end{aligned} \tag{8}$$

where:
P_K: active power of bus k, P_m : active power (bus m)
Q_K: reactive power (bus k), Q_m : reactive power (bus m)
V_K, V_m: voltage magnitudes of bus k and bus m, respectively
B_{Km}, B_{mK}: substances between connecting buses k and m
G_{Km}, G_{mK}: conductance between buses k and m, respectively
B_{mm}, B_{KK}: substances of bus k and bus m, respectively
G_{mm}, G_{kk}: conductance at bus k and n
series converter

$$\begin{aligned} P_{cR} = {} & V_{cR}^2 G_{mm} + V_{cR} V_K[G_{km}\cos(\delta_{cR}-\theta_K) + B_{Km}\ \delta\text{in}(\delta_{cR}-\theta_K)] \\ & +V_{cR} V_m[G_{mm}\ cos(\delta_{cR}-\theta_m) + B_{mm}\ \delta in(\delta_{cR}-\theta_m) \end{aligned} \tag{9}$$

$$\begin{aligned} & Q_{cR} = -V_{cR}^2\, B_{mm} + V_{cR} V_K[G_{Km}\delta in(\delta_{cR}-\theta_K) - B_{Km}\cos(\delta_{cR}-\theta_K)] \\ & +V_{cR} V_m[G_{mm}\delta in(\delta_{cR}-\theta_{mm}) - B_{mm}\cos(\delta_{cR}-\theta_m) \end{aligned} \tag{10}$$

shunt converter

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_K[G_{vR}\cos(\delta_{vR}-\theta_K) + B_{vR}\delta in(\delta_{vR}-\theta_K)] \tag{11}$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_K\ [G_{vR}\delta in(\delta_{vR}-\theta_K) - B_{vR}\cos(\delta_{vR}-\theta_K)] \tag{12}$$

$$\Delta P_{bb} = P_{vR} + P_{cR} = 0 \tag{13}$$

$$P_{vR} + P_{cR} = P_K + P_m = 0 \tag{14}$$

where:
P_{c_R}, P_{v_R}: series and shunt converters active power, respectively
Q_{cR}, Q_{vR}: series and shunt converters reactive power, respectively
ΔP_{bb} : represent the power mismatch

$$\begin{bmatrix} \Delta P_K \\ \Delta P_m \\ \Delta Q_K \\ \Delta Q_m \\ \Delta P_{mK} \\ \Delta Q_{mK} \\ \Delta P_{bb} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_K}{\partial \theta_K} & \frac{\partial P_K}{\partial \theta_m} & \frac{\partial P_K}{\partial V_{vR}} V_{vR} & \frac{\partial P_K}{\partial V_m} V_m & \frac{\partial P_K}{\partial \delta_{cR}} & \frac{\partial P_K}{\partial V_{cR}} V_{cR} & \frac{\partial P_K}{\partial \delta_{vR}} \\ \frac{\partial P_m}{\partial \theta_K} & \frac{\partial P_m}{\partial \theta_m} & 0 & \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \delta_{cR}} & \frac{\partial P_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_K}{\partial \theta_K} & \frac{\partial Q_K}{\partial \theta_m} & \frac{\partial Q_K}{\partial V_{vR}} V_{vR} & \frac{\partial Q_K}{\partial V_m} V_m & \frac{\partial Q_K}{\partial \delta_{cR}} & \frac{\partial Q_k}{\partial V_{cR}} V_{cR} & \frac{\partial Q_K}{\partial \delta_{vR}} \\ \frac{\partial Q_m}{\partial \theta_K} & \frac{\partial Q_m}{\partial \theta_m} & 0 & \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \delta_{cR}} & \frac{\partial Q_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{mK}}{\partial \theta_K} & \frac{\partial P_{mK}}{\partial \theta_m} & 0 & \frac{\partial P_{mK}}{\partial V_m} V_m & \frac{\partial P_{mK}}{\partial \delta_{cR}} & \frac{\partial P_{mK}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_{mK}}{\partial \theta_K} & \frac{\partial Q_{mK}}{\partial \theta_m} & 0 & \frac{\partial Q_{mK}}{\partial V_m} V_m & \frac{\partial Q_{mK}}{\partial \delta_{cR}} & \frac{\partial Q_{mK}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{bb}}{\partial \theta_K} & \frac{\partial P_{bb}}{\partial \theta_m} & \frac{\partial P_{bb}}{\partial V_{vR}} V_{vR} & \frac{\partial P_{bb}}{\partial V_m} V_m & \frac{\partial P_{bb}}{\partial \delta_{cR}} & \frac{\partial P_{bb}}{\partial V_{cR}} V_{cR} & \frac{\partial P_{bb}}{\partial \delta_{vR}} \end{bmatrix} \begin{bmatrix} \Delta \theta_K \\ \Delta \theta_m \\ \frac{\Delta V_{vR}}{V_{vR}} \\ \frac{\Delta V_m}{V_m} \\ \Delta \delta_{cR} \\ \frac{\Delta V_{cR}}{V_{cR}} \\ \Delta \delta_{vR} \end{bmatrix} \tag{15}$$

$$\begin{bmatrix} \Delta P_K \\ \Delta P_m \\ \Delta Q_K \\ \Delta Q_m \\ \Delta P_{mK} \\ \Delta Q_{mK} \\ \Delta P_{bb} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_K}{\partial \theta_K} & \frac{\partial P_K}{\partial \theta_m} & \frac{\partial P_K}{\partial V_K} V_K & \frac{\partial P_K}{\partial V_m} V_m & \frac{\partial P_K}{\partial \delta_{cR}} & \frac{\partial P_K}{\partial V_{cR}} V_{cR} & \frac{\partial P_K}{\partial \delta_{vR}} \\ \frac{\partial P_m}{\partial \theta_K} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial V_K} V_K & \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \delta_{cR}} & \frac{\partial P_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_K}{\partial \theta_K} & \frac{\partial Q_K}{\partial \theta_m} & \frac{\partial Q_K}{\partial V_K} V_K & \frac{\partial Q_K}{\partial V_m} V_m & \frac{\partial Q_K}{\partial \delta_{cR}} & \frac{\partial Q_K}{\partial V_{cR}} V_{cR} & \frac{\partial Q_K}{\partial \delta_{vR}} \\ \frac{\partial Q_m}{\partial A_K} & \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial V_K} V_K & \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \delta_{cR}} & \frac{\partial Q_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{mK}}{\partial \theta_K} & \frac{\partial P_{mK}}{\partial \theta_m} & \frac{\partial P_{mK}}{\partial V_K} V_K & \frac{\partial P_{mK}}{\partial V_m} V_m & \frac{\partial P_{mK}}{\partial \delta_{cR}} & \frac{\partial P_{mK}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_{mK}}{\partial \theta_K} & \frac{\partial Q_{mK}}{\partial \theta_m} & \frac{\partial Q_{mK}}{\partial V_K} V_K & \frac{\partial Q_{mK}}{\partial V_m} V_m & \frac{\partial Q_{mK}}{\partial \delta_{cR}} & \frac{\partial Q_{mK}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{bb}}{\partial \theta_K} & \frac{\partial P_{bb}}{\partial \theta_m} & \frac{\partial P_{bb}}{\partial V_K} V_K & \frac{\partial P_{bb}}{\partial V_m} V_m & \frac{\partial P_{bb}}{\partial \delta_{cR}} & \frac{\partial P_{bb}}{\partial V_{cR}} V_{cR} & \frac{\partial P_{bb}}{\partial \delta_{vR}} \end{bmatrix} \begin{bmatrix} \Delta \theta_m \\ \frac{\Delta V_K}{V_K} \\ \frac{\Delta V_m}{V_m} \\ \Delta \delta_{cR} \\ \frac{\Delta V_{cR}}{V_{cR}} \\ \Delta \delta_{vR} \end{bmatrix} \tag{16}$$

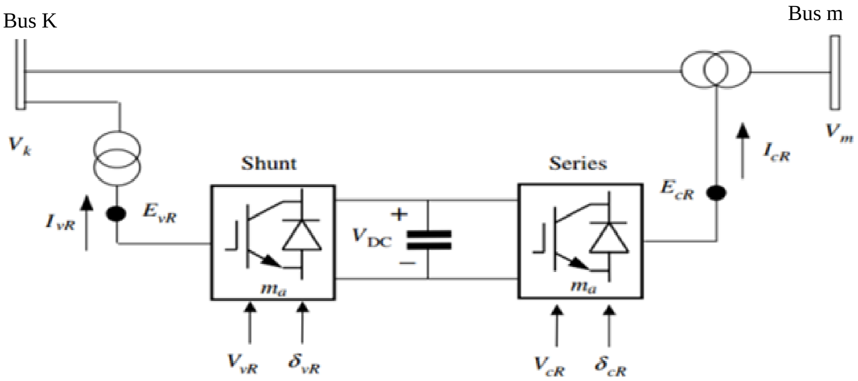

Figure 1. The basic scheme of UPFC

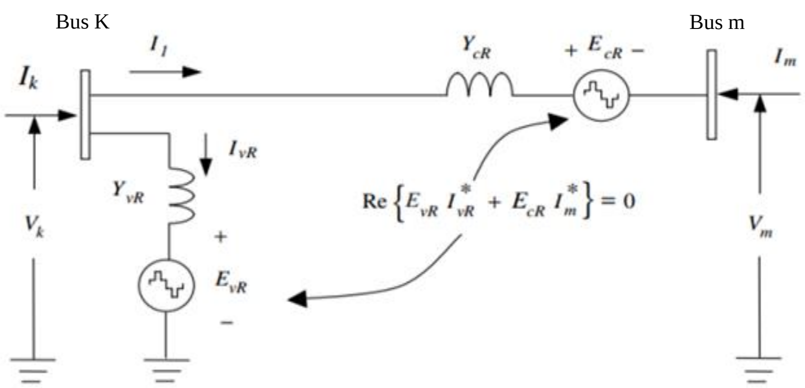

Figure 2. The electrical model of UPFC

2.2. Particle swarm optimization

Kennedy and Eberhart [27] proposed a PSO algorithm. This algorithm could be found in the congestion intelligence branch. This algorithm allows users to share knowledge and experiences. Simulating simplified versions of society was used to generate PSO [28]. The following is how the system works [29]:
- The process is used to research swarms like fish schools and flocks of birds.
- It is founded on basic ideas. As a result, it only uses a small amount of memory and computes quickly.
- It was designed for non-linear optimisation problems with continuous variables initially.

The velocity may be used to express this modification, and the following can be used to change the speed of each agent [30], [31]:

$$V_{id}^{Ko+1} = wV_{id}^{Ko} + C_1 \times \mathrm{rand}\left(Pbest_{\,id} - X_{id}^{ko}\right) + C_2 \times rand\left(Gbest_{\,id} - X_{id}^{ko}\right) \tag{17}$$

$$X_{id}^{ko+1} = X_{id}^{ko} + V_{id}^{ko+1} \tag{18}$$

where:
i=1,2,3…….n, d=1,2,3…….m, n. Group's number of particles, m particle members
X_{id}^{ko} *and* X_{id}^{ko+1} represent a current and modified searching point,$V_{id}^{Ko}$and V_{id}^{Ko+1} represents the current velocity and modified velocity, V_{pbest} and V_{gbest} represents velocity based on p_{best} and g_{best}
$Pbest$ i_{th} particle's best position, $Gbest$ is the group's best particle, w_i the agent's weight function velocity,
C_1, C_1 : Acceleration constant:

$$w_{(\mathrm{i})} = w_{max} - \left(\frac{w_{max}-w_{min}}{\mathrm{k}o_{max}}\right) * k_0 \tag{19}$$

where:
w_{max}, w_{min}: represent maximum and minimum weight
k_0 , $\mathrm{k}o_{max}$: represent current iteration and maximum, respectively

In this paper, the proposed PSO-based optimum PI controller with UPFC system and location design procedure is shown in Figure 3. The flow chart of this proposal is shown in Figure 4. The PSO parameters used in the proposed work are given in Table 1.

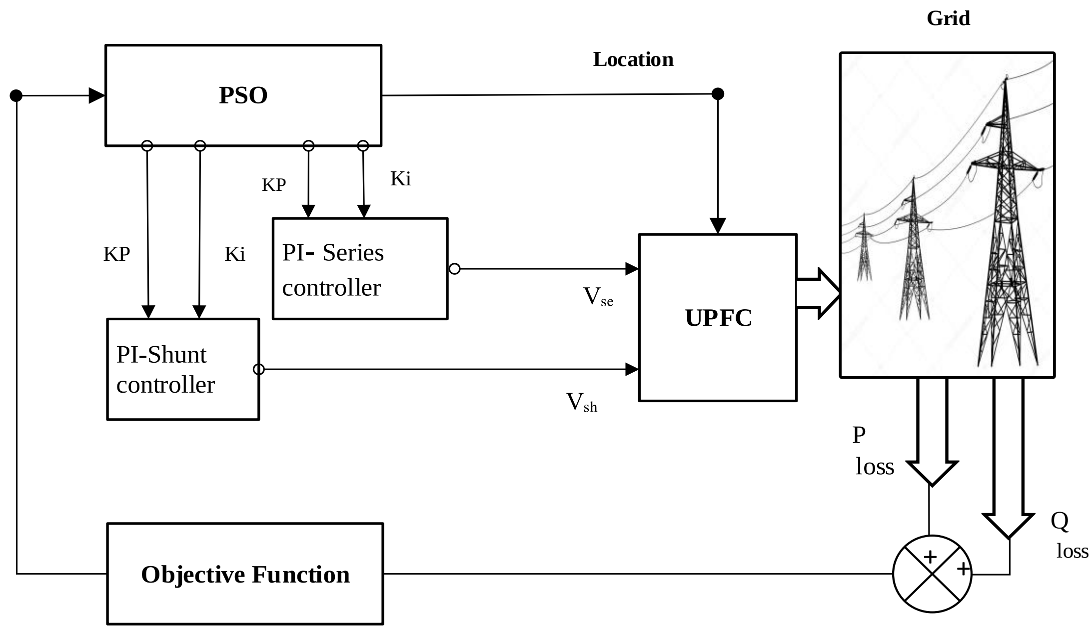

Figure 3. The proposed PSO-based optimum PI controller with UPFC system and location design procedure

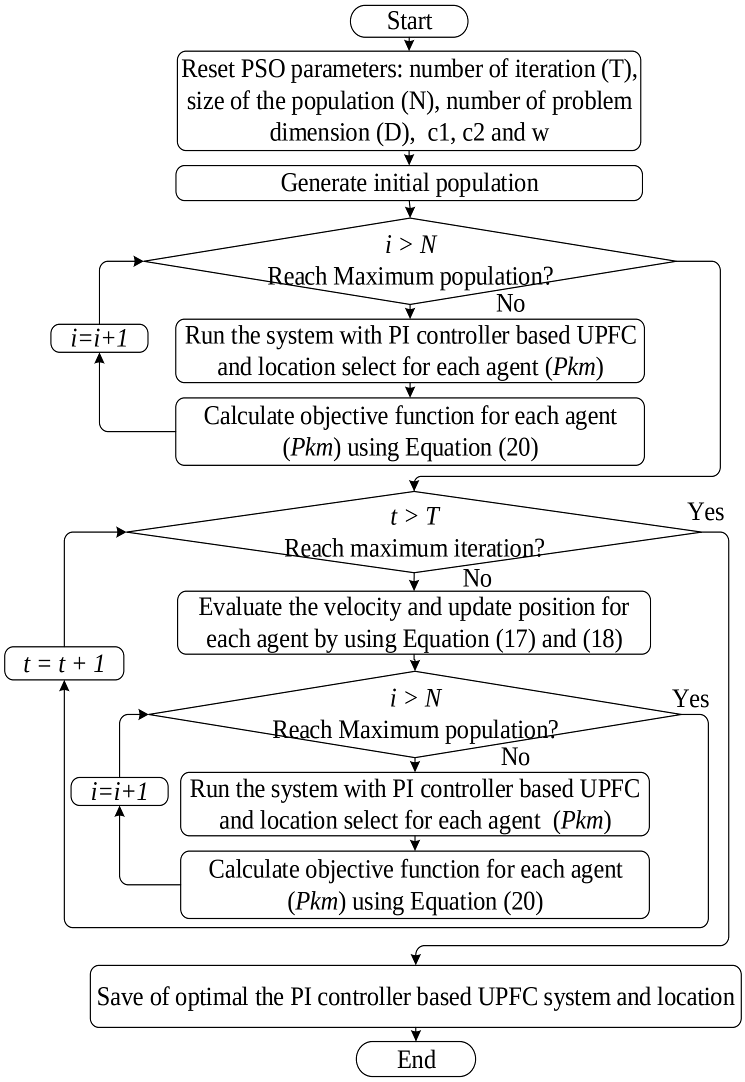

Figure 4. Flow chart of the proposed PSO-based optimum PI controller with UPFC system and location design procedure

Table 1. The parameters of PSO

Parameters of PSO	
Number of particles	20
Number of iterations	100
Number of variables	5
C1, C2	1.5
W	0.5

2.3. Proportional-integral controller

The approach of selecting the parameter settings (proportional and integral) gains of the PI controller of the series and shunt converter should be chosen to increase the regulated process's stability [32]. Control loop tuning is adjusting the system parameters to achieve the best possible system outputs. From Figure 3, (Kp) represent proportional gain, (Ki) means integral gain, (V_{se}) describe the magnitude of the UPFC series voltage source converter, and (V_{sh}) represents the magnitude of the UPFC shunt voltage source converter. Each particle from the PSO search for five variables of the system, the parameters of controller Kp and Ki of the two converters series and shunt, and the optimal location of the UPFC. The total power flow losses for each particle population of the grid with UPFC were obtained from the Newton Raphson method by MATLAB code.

3. RESULTS AND DISCUSSION

The ING (46-bus) was used as the case study; the system consists of 22 generator buses and 42 load buses. Figure 5 shows the single-line diagram of the ING system. The following approach has been implemented on the ING system: two scenarios have been examined:

- Case 1: pre-optimization (without UPFC)
- Case 2: losses minimisation with UPFC installation using PSO proposed

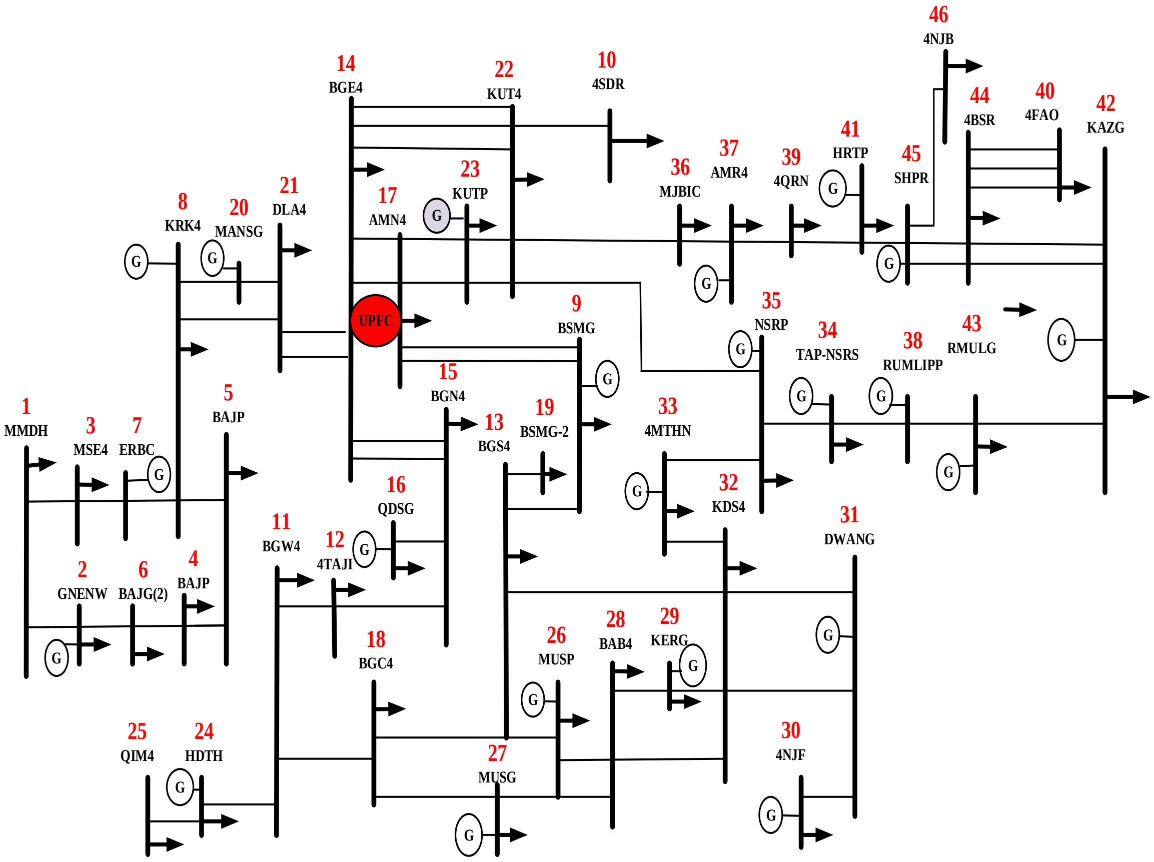

Figure 5. ING's single-line diagram

3.1. Case 1: pre-optimization (without UPFC)

The ING (400 kV) systems are employed as test systems to validate the proposed PSO algorithm. The PSO algorithm is written in the computer programming language MATLAB. There were 73 transmission lines, bus 23 (KUTP) is the slack bus in this situation, and the ING data is based on the Iraqi Ministry of Electricity database. By modelling the ING in the MATLAB code program, the system's total active and reactive losses are 727.4593 MW, total reactive losses are 5155.9 MVAR, and total apparent power is 5207 MVA.

3.2. Case 2: losses minimization with UPFC installation using PSO proposed

The Newton-Raphson method was employed to perform load flow analysis, and loss minimization of active and reactive power losses was chosen as this work's primary goal by (20):

$$objective\ function = \sum_{i=1}^{Nb} min\ (S_{loss}) \tag{20}$$

S_{loss} represent the total active and reactive power loss of the lines, and Nb: is the number of the transmission lines. The response of the objective function is shown in Figure 6. The PSO algorithm with PI controller suggests installing UPFC on buses (14-17), BGE4 (Baghdad)-AMN4 (Baghdad). The active and reactive power losses of the lines without UPFC and UPFC-based PSO-PI are shown in Figures 7 and 8.

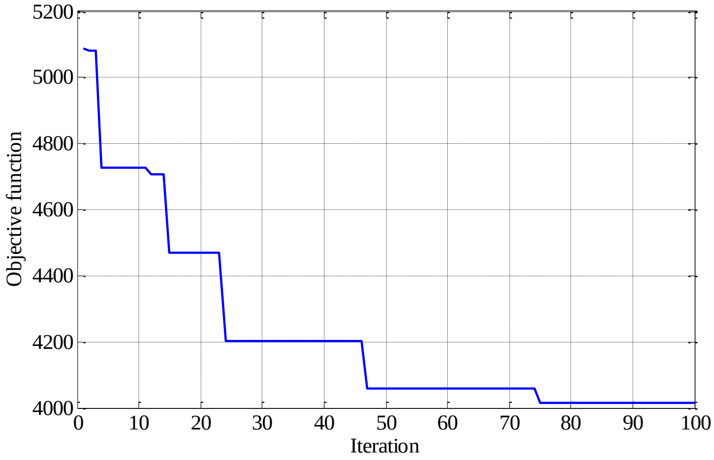

Figure 6. The response of the objective function

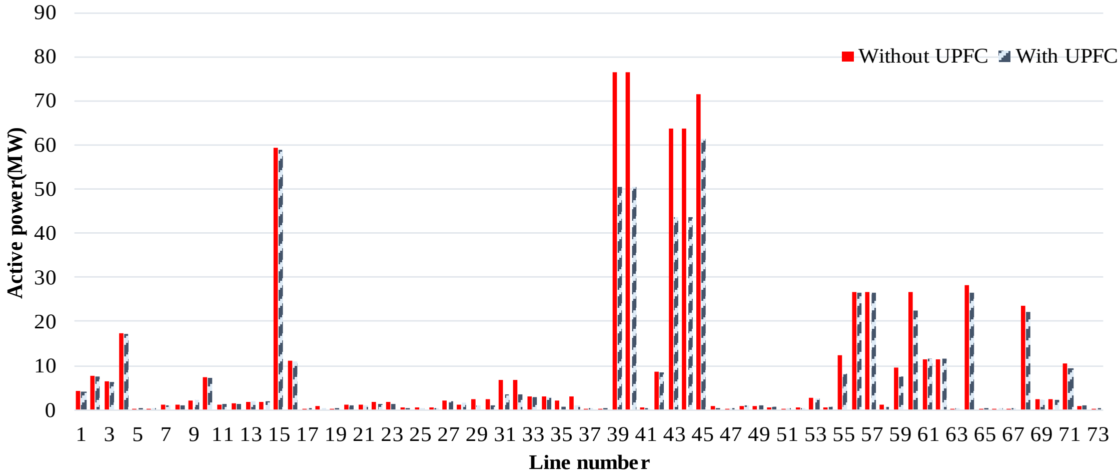

Figure 7. The active power losses

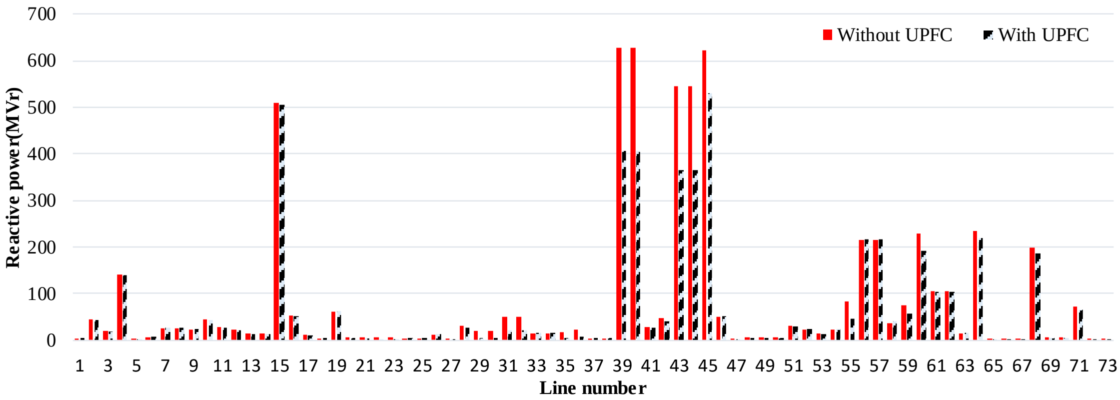

Figure 8. The reactive power losses

Figure 9 illustrates the system's active losses decreased from 727.4593 to 579.3449 MW, while the reactive losses decreased from 5155.9 to 39711 MVAR, as shown in Table 2, an improvement in loss of 19% and 23%, respectively. The results of the optimization are in Table 3. The reduction in losses improves the voltage magnitude of the buses, as shown in Figure 10.

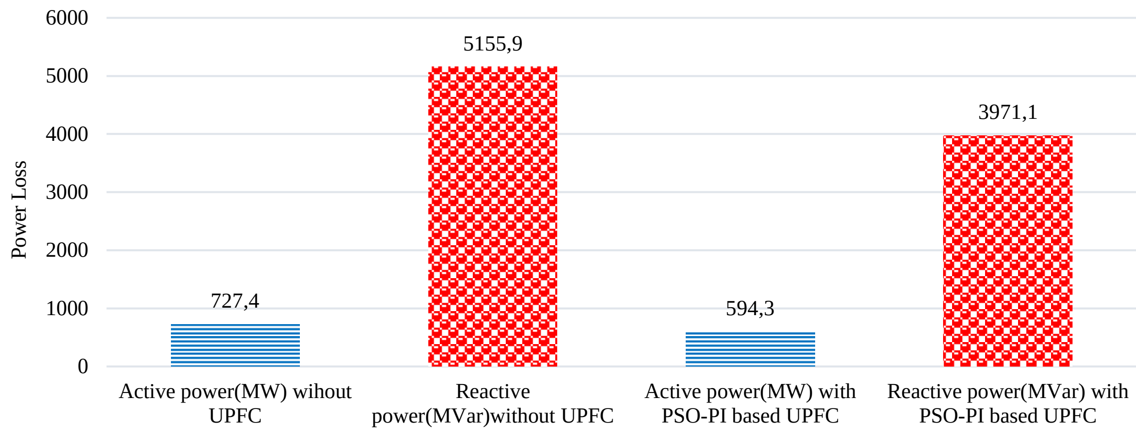

Figure 9. Total active and reactive power losses

Table 2. The total amount of active and reactive losses both before and after compensation

Losses	Without UPFC	with UPFC (PI-PSO)	Improvement (%)
P total (MW)	727.4593	594.3449	19
Q total (MVAR)	5155.9	3971.1	23
S total (MVA)	5207	4015.3	23

Table 3. The results of the proposed optimisation

PI parameters				Location of UPFC
Kp_s	Ki_s	Kp_{sh}	Ki_{sh}	(14-17)
0.0016	6.82e-04	0.1076	0.0382	BGE4-AMN4

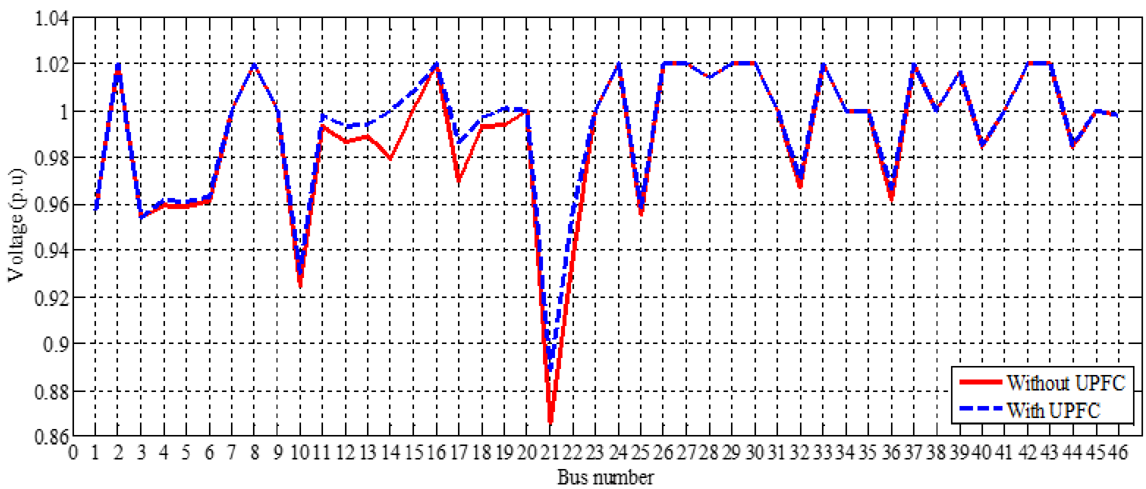

Figure 10. Voltage magnitude in p.u. with and without UPFC

4. CONCLUSION

The paper proposes an optimized PI controller to control the UPFC. In the proposed system, a PSO algorithm was used to find the optimum values of PI gains and the optimal location of the UPFC. This proposed method was tested on the ING system. The results show good performance has been achieved in minimizing losses. The optimal location of the UPFC was between bus 14 and bus 17, which was named BGE4 (Baghdad)-AMN4 (Baghdad), and the total active power and reactive power losses of the ING power system decreased from 727.4593 to 579.3874 MW and from 5155.9 to 3971.1 MVAR, respectively. As a result, voltage regulation was achieved. The future study can replace the PI controller with a fuzzy logic controller and compare the results from the two controllers.

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